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Teachers' Beliefs about the Role of Interaction in Teaching Newtonian Mechanics and Its Influence on Students' Conceptual Understanding of Newton's Third Law

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ABSTRACT *Students' conceptual understanding of Newton's third law has been the subject of numerous studies. These studies have often pointed out the importance of addressing the concept of interaction in teaching Newtonian mechanics. In this study, teachers were interviewed in order to examine how they understand interaction and use it in their instruction. The results show that teachers have a wide variety of beliefs about interaction. Moreover, by using the Force Concept Inventory test the understanding of Newton's third law by the teachers' students was tested. According to the results, the explicit use of interaction as a guiding principle in mechanics instruction helps students understand Newton's third law.*

KEY WORDS: *Dominance principle, Newtonian mechanics, students' conceptions, teachers' beliefs*

Introduction

Numerous studies (e.g., Maloney, 1984; Terry & Jones, 1986; Brown, 1989) demonstrated that based on intuition and years of experience with moving bodies, students tend to think of force as a property of an object and consider a situation with two bodies asymmetrically. That is, in an interaction, if the masses of the bodies differ, students often expect that the greater or the more active one exerts a greater force on the other. Halloun and Hestenes (1985b) refer to this conception as the *dominance principle.* These conceptions of force are deeply rooted, everyday experiences give support to them, and often instruction fails to produce change in them (see, for example the references in McDermott & Redish, 1999). Because of this, students face difficulties in understanding the basic concepts of mechanics and Newton's laws of motion, such as Newton's third law.

The concept of interaction, although not always explicitly expressed in the original works of Newton and in its subsequent interpretations, was nevertheless a central theme in the development of Newtonian mechanics (see e.g., Jammer,

1957/1999). The most transparent and far extending formulation of the general idea of interacting bodies and their relation to Newtonian forces is contained in Helmholtz's conception of mechanics, which clarified the concepts of force and energy (Jammer, 1957/1999; Heidelberger, 1993). According to Helmholtz's reconstruction of the Newtonian view, forces arise from interactions between two objects, and a force does not exist except when arising from the interaction between two objects (Heidelberger 1993; see also Brown, 1989). From this viewpoint, Newton's theory is constructed to describe the effects of interaction, and Newton's laws enable to make the force a quantity measuring the strength of the interaction between two objects. However, it is now customary to introduce the concepts of mechanics essentially in a form of a 'one body problem' removed from the natural context of interaction between two bodies, a view that has its roots in the 18th century formulation of Newtonian mechanics. This view, although in many ways concise and efficient, may nevertheless be connected to students' difficulties with symmetry of interaction and Newton's third law, because it is a view that presupposes a rather abstract level of thinking. Unfortunately, this historical choice is reflected in many textbook presentations, and little thought is often given to the view that the force as a concept belongs inherently to the two-body interaction problem.

Many studies focused on students' conceptions about force and understanding of Newton's third law. These studies often suggest that it is important for students to understand that forces arise from interaction between two objects (e.g., Terry & Jones, 1986; Brown, 1989). The present study focuses on teachers' beliefs about the role of interaction in teaching of Newtonian mechanics. In this study, we clarify how physics teachers experience, understand, and apprehend the concept of interaction, while teaching Newtonian mechanics in upper secondary schools. Moreover, it is investigated how these teachers' beliefs influence students' conceptual understanding of interaction and Newton's third law, and how they apply the law when solving simple problems of Newtonian mechanics.

The question of what kind of knowledge a physics teacher, expert of physics, and physics teaching and learning needs has been asked many times. One useful definition of this knowledge is a definition of the pedagogical content knowledge (PCK) introduced by Shulman (1987). With this PCK, a teacher can integrate in a teaching-learning situation his or her physics knowledge, knowledge and skills of using different teaching models (learning or instructional methods, models, strategies or classroom practices), assessment methods, and knowledge about students' learning and their previous knowledge (Carlsen, 1999; Bransford & Brown & Cocking, 2000, 3-27). In this paper, we are interested in one area of PCK: teachers' beliefs of interaction, its role as a main organizing concept of Newtonian mechanics, and its possibilities to help students form an understanding of interaction and an ability to use it in problem solving.

The specific research questions were:

1. What are the teachers' beliefs concerning mutual interaction and of the importance of introducing interacting bodies instead of a single body in teaching Newtonian mechanics?
2. How do these teachers' beliefs influence students' conceptual understanding of Newton's third law?

Method and Sample

The data were collected during 1999-2000 in Finnish upper secondary schools. The sample of the study consisted of 18 upper secondary school physics teachers and their 386 students (29% females, 71% males) from 18 different schools. On average, 21-22 students from each school took part in the study. Four schools were located in the capital area of Helsinki, 10 in other cities located both in South- and North-Finland, and 4 schools in rural areas.

The teachers participated as volunteers in the research. Information about the research was spread through an e-mail list for physics teachers. In addition, letters, e-mails, and faxes were sent to physics teachers in the capital region of Finland. Eleven out of eighteen participating teachers had taken part in an extensive in-service training program (described in Lavonen, Jauhiainen, Koponen, & Kurki-Suonio, 2004) or corresponding university level courses. The role of experiments in teaching physics was the focus in the program, and, therefore, the teachers had to plan experiments that support conceptual understanding of basic concepts, and laws including interaction and Newton's third law. Interaction was discussed as having important role in the conceptual structure of mechanics. In addition to those eleven teachers that took part in the teacher training program, the remaining seven can also be considered as expert teachers, and, therefore, more aware than an average teacher, since they have been involved in writing textbooks or working as mentor teachers in teacher training. Because participation in this type of study was voluntary, the teachers and their students were not a random sample. Thus, the results of the study can only cautiously be generalised.

The first research question was answered on the basis of teacher interviews that lasted approximately 30 minutes and took place after mechanics instruction. The interviews were analysed according to qualitative research methods. To ensure conditions of minimal guiding, it was decided to use unstructured interviews (Fontana & Frey, 2005). Thus, the interviews were informal and flexible. In the interviews, the researcher began with general questions concerning teaching mechanics, teachers' practices, practical work, students, etc. The interviewer tried to avoid direct questions, but if the teacher did not spontaneously start talking about interaction and its role in teaching mechanics, the interviewer moved on to more specific questions in order to clarify the teacher's beliefs. It was expected that this type of discussion promotes more reflectivity, and leads the teachers to express their beliefs. All the interviews were recorded on audiotape and transcribed according to conventional procedures.

After transcribing the interviews, one researcher read the interviews several times, using the purpose of this study and the research questions as initial guides, and organised the data first according to the topic, and reduced it by distinguishing the relevant issues from the not so relevant ones. Then, teachers' responses were coded and categorized by the same researcher. The researcher focused on similarities and differences between ways in which the participants had responded. Consequently, the categories that were the result of the analysis arose from the data (cf. Huberman & Miles, 1994). The process involved continual readings of the interviews, and the analysis went through several runs. The researcher who made the categorisation explained the process and the results of the categorisation, and demonstrated how the categorisation was made to the other researchers, who final-

ly confirmed that the results were based on the original data.

Students' conceptual understanding of Newton's third law was measured with the subset of items of the Force Concept Inventory (FCI), a multiple-choice test, designed by Hestenes, Wells, and Swackhamer (1992). This took place after the students had completed their introductory units on forces including studies of basic kinematics, dynamics and the Newton's laws of motion. The teachers were given the FCI items just before the testing of the students, so it was not possible for the teachers to teach or give any advice with regards to the test, and thus influence the results of the FCI items. The FCI, which probes students' conceptions on Newtonian mechanics, especially the concept of force, as well as students' ability to apply basic concepts and laws of Newtonian mechanics in various contexts, consists of 30 qualitative, multiple-choice questions. The test is designed based on extensive research results on students' common-sense conceptions about motion (Halloun & Hestenes, 1985a). The description of the validation process and the reliability of the test is provided by Halloun and Hestenes (1985b). In summary, the content validity of the test was established by discussing the test with physics professors and graduate students, as well as by interviewing introductory physics students in order to find out that the questions were understood correctly. The reliability of the test was achieved by student interviews, which confirmed that students chose the same alternatives repeatedly, and by statistical analysis of the test results. (Halloun & Hestenes 1985b)

In this study, four items of the FCI were used. These items, which appear in the appendix to this article, were designed to probe for the ability to apply Newton's third law, or, on the other hand, reveal the *dominance* principle (Hestenes, Wells, & Swackhamer 1992). In the first question (number 4 in the original test), a situation is described where a large truck collides with a small car. In the second question (number 28), two students are sitting on office chairs. One of them has his feet on the knees of the other student, and pushes outward with his feet. The other two questions consider a more complicated context. In these questions, systems in motion, with constant velocity (question 15) and constant acceleration (question 16), are described. In all of these questions, the students are asked to compare the forces the different parties exert on each other. The number of correct answers for the questions described above (maximum 4) was used as a measure for conceptual understanding of Newton's third law.

In order to search for dependencies between students' conceptual understanding and teachers' beliefs, the results of the four items of the FCI from different schools were compared. This was done with the Independent-Samples *t*-test (two-tailed) and as an additional check, the power of the difference was tested with Cohen's d ($d = M_g - M_b / S.D._{pooled}$, where $S.D._{pooled} = [(S.D_g^2 + S.D_b^2) / 2]$ (Cohen, 1988). The Independent-Samples *t*-test procedure compares means for two groups and Cohen's d measures the effect size for the difference: no effect at $d < 0.2$, small effect at $0.2 < d < 0.5$, moderate effect at $0.5 < d < 0.8$, and large effect at $d \geqslant 0.8$.

Results

Teachers' Beliefs about the Concept of Interaction

The interviews revealed that teachers use the concept of interaction in diffe-

rent roles in physics instruction. Roughly, the teachers interviewed can be divided into teachers who use the concept of interaction as a basic organizing concept in teaching Newtonian mechanics, and into teachers who do not implement interaction in mechanics instruction. However, inside these two categories, there are differences about how much the teachers emphasize the concept of interaction in their instruction, and, moreover, how do they understand the role of interaction in teaching Newtonian mechanics. In the following, the two main categories and the subcategories are described.

Category 1: *Interaction Is Understood in a Restricted Sense, and not Implemented in the Instruction of Mechanics.*

In the first main category, the teachers do not systematically use interaction in teaching Newtonian mechanics. They may briefly mention the concept of interaction, but they do not emphasize it in their instruction. Four teachers out of the 18 participating teachers (i.e., 22%) can be placed in this category. These teachers failed spontaneously to mention interaction when discussing the central themes in mechanics instruction.

Subcategory 1.1: *Interaction Is Understood in a Restricted Sense.*

In the interviews, the responses of two teachers revealed that they understand interaction in a restricted sense (i.e., gravitation, electromagnetic, weak, and strong interaction), but not as a general principle in mechanics. Consequently, the concept of interaction does not appear in their instruction until the course of modern physics. The following excerpt from one interview illustrates this category:

> *In the course of modern physics, we summarize all the interactions as well as the particles mediating the interactions.*

Category 2: *Interaction Is Considered as a Basic Organizing Concept In Mechanics Which Explains Changes in the State of Motion.*

The majority of the teachers (14 out of 18, i.e., 78%) interviewed used the concept of interaction in teaching Newtonian mechanics, and introduced force as something representing the strength of interaction. The following excerpt illustrates this category in general

> *I have started very much from the fact that force is in a way the gauge for interaction. And if we want to change the body's state of motion, we need an interaction to cause it.*

Subcategory 2.1: *The Concept of Interaction Is not Fully Understood.*

In the second main category, there is much difference in how the teachers emphasized and adopted the concept of interaction. In the interviews, 10 teachers out of 14 in the second main category, failed to explain in detail how they use interaction in their instruction, nor could they give any reasons why they think it is important to use it. In few cases, the responses of the teachers were unclear and not precise enough to give a clear picture of how the teachers actually understand the concept. Thus, although the teachers stated that the concept of interaction has a central part in their instruction, the interviews revealed that they had not fully adopted the concept. They stress the concept of interaction in general, but do not use the concept when they explain how they solve problems of Newtonian mecha-

nics, and how they help students to recognise forces acting on an object. These teachers are placed in the subcategory 2.1. Seven of the teachers had participated in the earlier mentioned in-service training program or had completed the corresponding courses (described in Lavonen, Jauhiainen, Koponen, & Kurki-Suonio, 2004) that also encouraged the use of the concept of interaction in teaching Newtonian mechanics. Consequently in the interviews, the respondents used vocabulary that was used in the training program, but the interviews revealed some uncertainty in how the teachers talked about using interaction in teaching Newtonian mechanics.

Subcategory 2.2: *The Concept of Interaction Is Systematically Used and Emphasized in the Instruction.*

In the interviews, four teachers spontaneously started talking about the role of the concept of interaction in their instruction. They explained how they start teaching Newtonian mechanics by introducing interaction; they named different interactions and classified them. Moreover, they described how they systematically use interaction throughout mechanics instruction. In addition, these teachers conceptualized the role and importance of interaction in teaching Newtonian mechanics. It can be concluded that these teachers had adopted the concept of interaction. Thus, these teachers can be placed in the subcategory 2.2. The following interview excerpt illustrates this subcategory in general:

> ***Interviewee:*** *We start with the interaction. That is the main thing, which these sketches look for. And usually when they (the students) finally deeply understand the interaction, how it influences, they start understanding what the action and reaction are.*
>
> ***Interviewer:*** *So, have you used the concept of interaction?*
>
> ***Interviewee:*** *That is where it starts. I have actually started the whole subject of physics with it, maybe not in the very first lesson, but almost. Without interaction nothing happens, this is the point which you have to start with.*

When solving mechanics problems, the teachers in this subcategory guide the students first to consider all the interactions the body is involved with, and then find the forces that describe these interactions. The next example demonstrates this.

> *We look for interactions, and when there is an interaction, there are also the forces. This is the concrete way we go through the problems. If you think there is a force involved in the problem, search the interaction, that illustrates the force.*

In addition, these teachers used demonstrations that illustrate the fact that there are always two parties in an interaction. This is unlike the teachers in subcategory 2.1 of whom only few described interaction demonstrations, like bodies falling down, where the influence of interaction can only be seen on one body.

The interviews also revealed that the teachers in subcategory 2.2 had been pondering about reasons to use interaction as a basic organizing principle in teaching Newtonian mechanics. They had noticed how it helps them teach and how it facilitates students' understanding. Consequently, these teachers have seriously engaged themselves in adopting interaction in their instruction.

Subcategory 2.2.1: *Students' Conceptions Are Taken into Account.*

One of the teachers in subcategory 2.2 differed from the other teachers in the

category in the way the teacher took students' previous conceptions into account. This teacher was aware of students' conceptions and started the introduction of a new concept by eliciting students' previous conceptions, and tried to produce a change in them. Thus, one teacher could be placed in subcategory 2.2.1. In this subcategory, the teacher, in addition to using interaction as a basic organising principle, also took students' initial beliefs and conceptions into account. This is supported by the following comment:

> *It is good to elicit their preconceptions of the matter. When you notice that their preconceptions are wrong, then you know that it is a big job to correct them.*

However, it should be pointed out that the interviewer did not pose any questions regarding students' conceptions, so it is possible that other teachers participating in the study were also aware of their students' conceptions about interaction, and also took them into account in their instruction.

The categories of teachers' beliefs of the concept of interaction are summarized in Table 1. Figures in parentheses indicate the number of teachers, whose responses fitted that category.

Table 1
Teachers' Beliefs of the Concept of Interaction.

Category 1	**Category 2**	
Interaction is not used in the instruction of mechanics. (4)	Interaction is considered as a basic organizing concept in mechanics, which explains changes in the state of motion, and thus used in the instruction of mechanics. (14)	
Subcategory 1.1	**Subcategory 2.1**	**Subcategory 2.2**
Interaction is understood in a restricted sense. (2)	The concept of interaction is not fully understood. (10)	The concept of interaction is systematically used and emphasized in the instruction. (4)
		Subcategory 2.2.1
		Students' conceptions are taken into account. (1)

To summarize, the majority of the teachers stated that they used the concept of interaction as having an essential role in teaching Newtonian mechanics. However, a minority of them exhibited a profound understanding of the concept, and were able to explain in detail how they used interaction in their instruction. These teachers used interaction systematically, started teaching mechanics by introducing it as a general principle, and deliberately used it as a guiding principle throughout.

In the first category, two of the four teachers had taken part in the in-service training, in the second category, nine out of fourteen and in the subcategory 2.2 two out of four. Thus, it can be concluded that participation in the training did not encourage all the teachers to use interaction in teaching Newtonian mechanics.

Students' Conceptual Understanding and Its Relation to Teachers' Beliefs

The results of the subset of four FCI items demonstrated that after instruction approximately one student out of three mastered Newton's third law in all contexts. Especially, many students believed that Newton's third law does not hold in a

dynamic situation. That is, they had difficulties in correctly answering questions 15 and 16 in the original FCI. Students' average score of the four questions (4, 15, 16, 28) in the FCI concerning Newton's third law was 2.4 (maximum 4) (SD = 1.3). That is, on average students participating in the research answered correctly 60% of the questions that probed the understanding of Newton's third law.

The average scores (means and standard deviations) of the students (n = 88) whose teachers did not use interaction in teaching mechanics (category 1, cf. Table 1) and of those (n = 122) whose teachers emphasized the concept and systematically used it in their instruction (category 2.2) are presented in Table 2. Moreover, the difference between these two groups is compared using the Independent-Samples t-test (two-tailed) and Cohen's d.

Table 2

Average Score of the Students' (n = 88) Whose Teachers Did Not Use Interaction in Teaching Mechanics, and of Those (N=122) Whose Teachers Emphasized the Concept and Systematically Used It in Their Instruction.

	Interaction has no role in teaching mechanics		Interaction as a general principle		t	d
	M_g	$S.D_g$	M_b	$S.D_b$	(1)	(2)
Students' success in items measuring conceptual understanding of Newton's third law	2.2	1.4	2.9	1.1	3.7***	0.56c

(1) ns p > 0.05, * p < 0.05, ** p < 0.01, *** p < 0.001
(2) A no effect (d < 0.2), B small effect (0.2 < d < 0.5), C moderate effect (0.5 < d < 0.8), D large effect ($d \geq 0.8$)

In the case where the teacher in addition to emphasising the concept of interaction also took students' previous conceptions of force into account (category 2.2.1), the students (n =19) achieved even higher average score of 3.3 (SD=1.0). Accordingly, the comparison of the FCI results from different schools suggest that paying attention to the concept of interaction in teaching as a general principle produces change in the students' dominance belief and increases understanding of Newton's third law.

Discussion and Conclusions

In this study, the complex interplay between teachers' beliefs and students' learning was addressed. The goal was to connect students' conceptual understanding of Newton's third law with their teachers' conceptions of the role of interaction in mechanics instruction. The results of the present study indicate that there are clearly differences in teachers' beliefs about the role and importance of interaction in mechanics instruction. Some teachers consider interaction as an important organising concept in teaching Newtonian mechanics and the instruction is based on the concept. Others agree with the importance of interaction, but they do not use it explicitly in their instruction. For some teachers, interaction does not play any role in the instruction of mechanics. These differences in teachers' beliefs and practices also have an effect on students' conceptual understanding of Newton's third law. According to the results, the explicit use of interaction as a guiding prin-

ciple throughout mechanics instruction impacts on students' conceptual understanding of Newton's third law. If teaching mechanics is based on the concept of interaction, students are guided to consider forces as something that represents the strength of interaction, demonstrations and practical work support these aspects, and students learn to use Newton's third law in mechanics problems.

The results of our study have clear implications for teaching. It is important to address the concept of interaction, develop mechanics instruction on the concept of interaction, and use it as a basic organizing concept throughout. Unfortunately, the current physics textbooks do not support this. Even, if the teachers consider it as important to use interaction as a general principle in teaching mechanics, they have difficulties in implementing it, because this is not done in the textbooks. Graphic representations emphasising the reciprocity of interactions can be useful (see for example, Jiménez-Valladares & Perales-Palacios, 2001; Savinainen & Scott & Viiri, 2005). In practical work and demonstrations, it is important to use rich contexts and variations, and emphasise the fact that the effects of interactions are seen in both parties of the interaction. In the demonstrations, it should be pointed out that the interaction is between two bodies, the interaction has simultaneously an effect on both parties of the interaction, and there are changes in the motions of the bodies. For example, collision demonstrations on an air track or students standing on skateboards can be useful. In these demonstrations, the mass and the activity of the parties should be varied.

This research has implications for teacher training also. The results show that although the use of interaction in teaching Newtonian mechanics is encouraged and discussed in the training program, teachers do have difficulties in implementing it in their instruction. It appears that if changing students' conceptions is difficult it is also difficult to change teachers' beliefs. Thus, it is important to study how teacher training should be organized in order to develop teachers' PCK.

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Appendix

4. A large truck collides head-on with a small compact car. During the collision

a) the truck exerts a greater amount of force on the car than the car exerts on the truck.

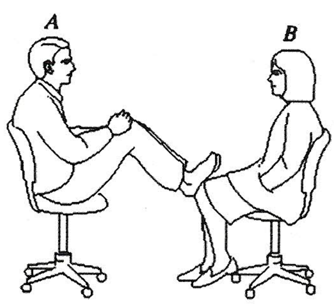
b) the car exerts a greater amount of force on the truck than the truck exerts on the car.

c) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.

d) the truck exerts a force on the car but the car does not exert a force on the truck.

e) the truck exerts the same amount of force on the car as the car exerts on the truck.

28. In the following figure, student *A* has a mass of 75kg and student *B* has a mass of 57kg. They sit in identical office chairs facing each other.



Student *A* places his bare feet on the knees of student *B*, as shown. Student *A* then suddenly pushes outward with his feet, causing both chairs to move.

During the push and while the students are still touching one another,

a) neither student exerts a force on the other.

b) student *A* exerts a force on student *B*, but *B* does not exert any force on *A*.

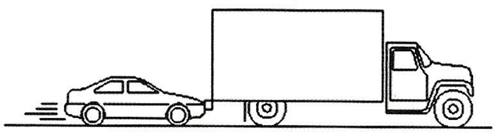
c) each student exerts a force on the other, but *B* exerts the larger force.

d) each student exerts a force on the other, but *A* exerts the larger force.

e) each student exerts the same amount of force on the other.

Use the statement and figure below to answer the next two questions (15 and 16).

A large truck breaks down out on the road and receives a push back into town by a small compact car as shown in the figure below.



15. While the car, still pushing the truck, is speeding up to get up to cruising speed,

a) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.

b) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.

c) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.

d) the car's engine is running so the car pushes against the truck, but the truck's engine is nor running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.

e) neither the car nor the truck exerts any force on the other. The truck is pushed forward simply because it is in the way of the car.

16. After the car reaches the constant cruising speed at which its driver wishes to push the truck,

a) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.

b) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.

c) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.

d) the car's engine is running so the car pushes against the truck, but the truck's engine is nor running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.

e) neither the car nor the truck exerts any force on the other. The truck is pushed forward simply because it is in the way of the car.